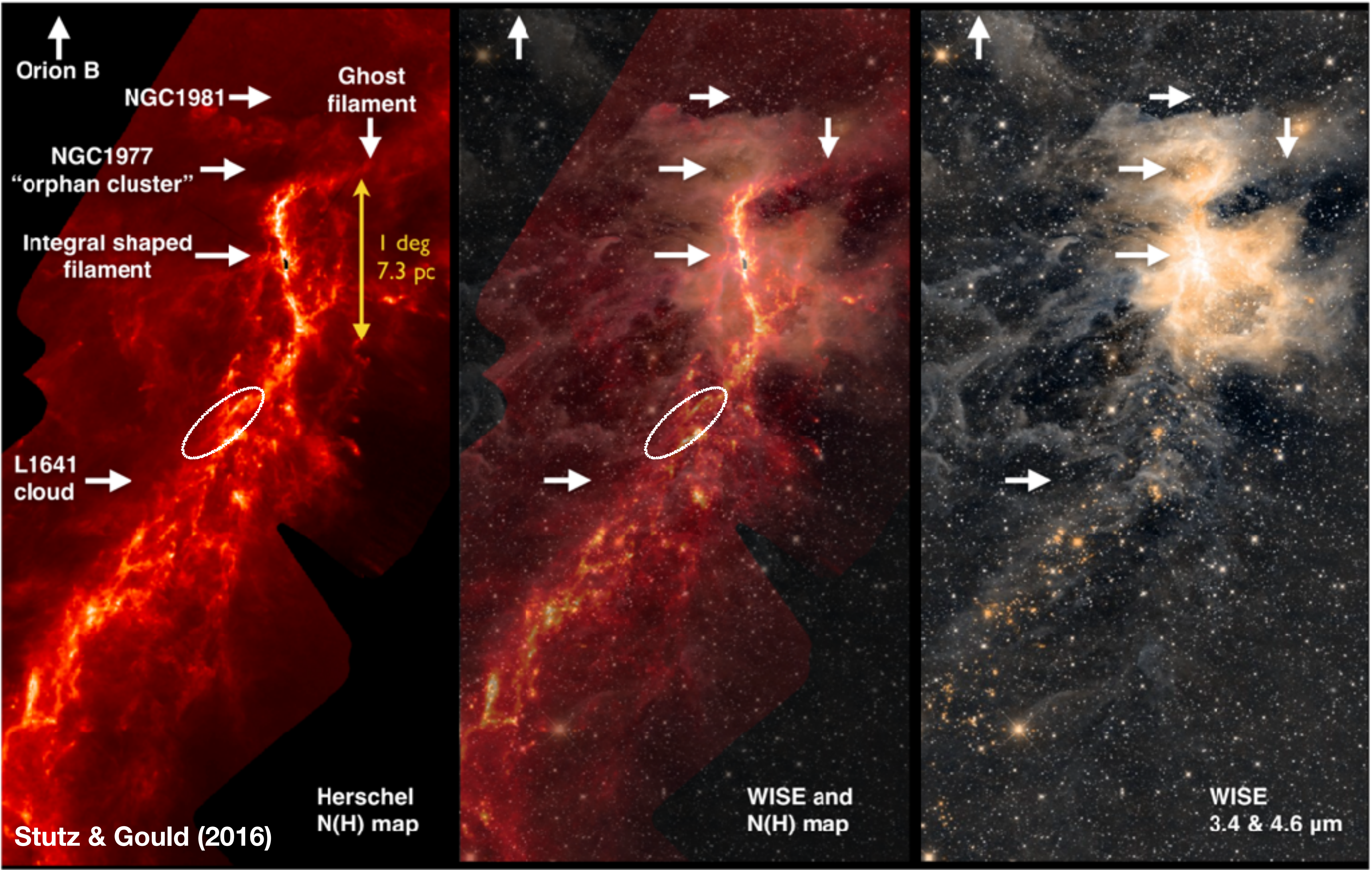
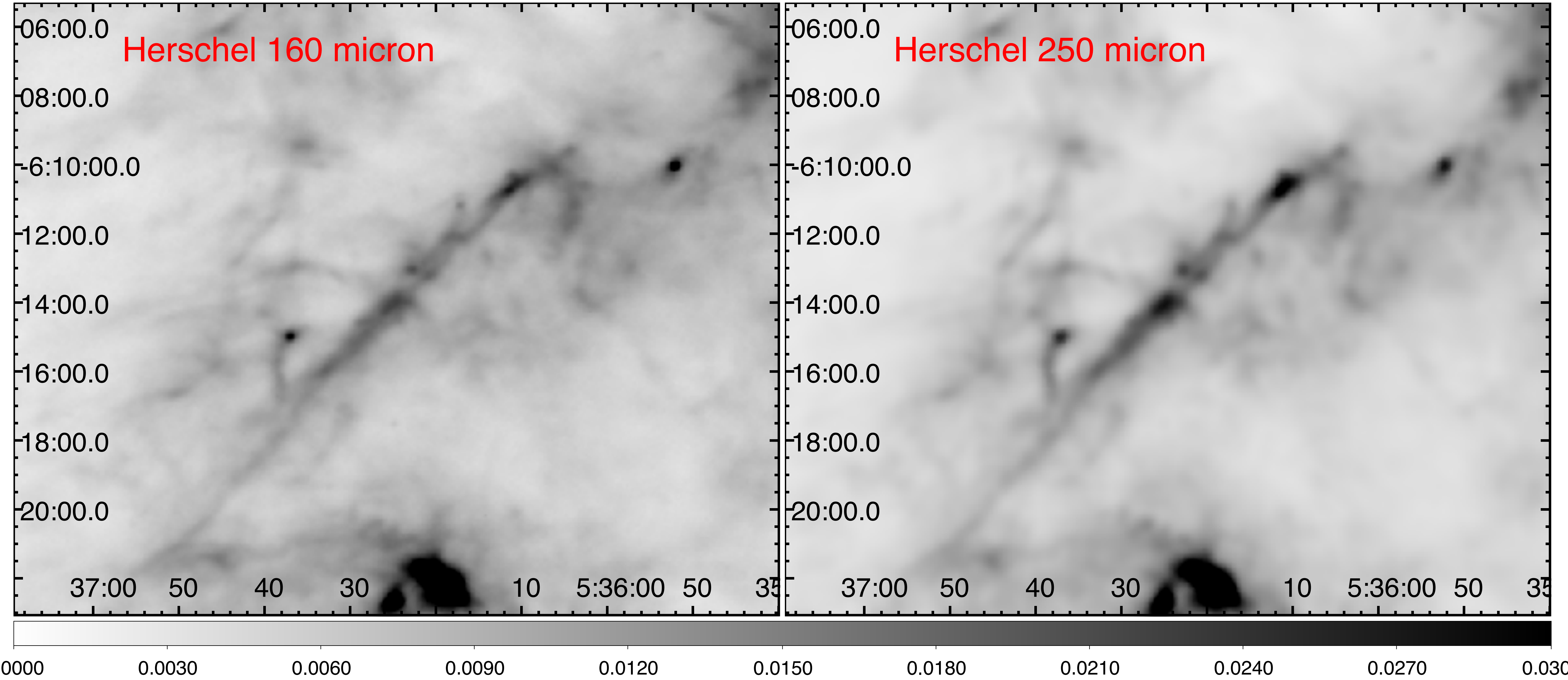
Filament Formation via Collision-induced Magnetic Reconnection - the Stick in Orion A (2021, ApJ, 906, 80)

Shuo Kong, Steward Observatory, University of Arizona



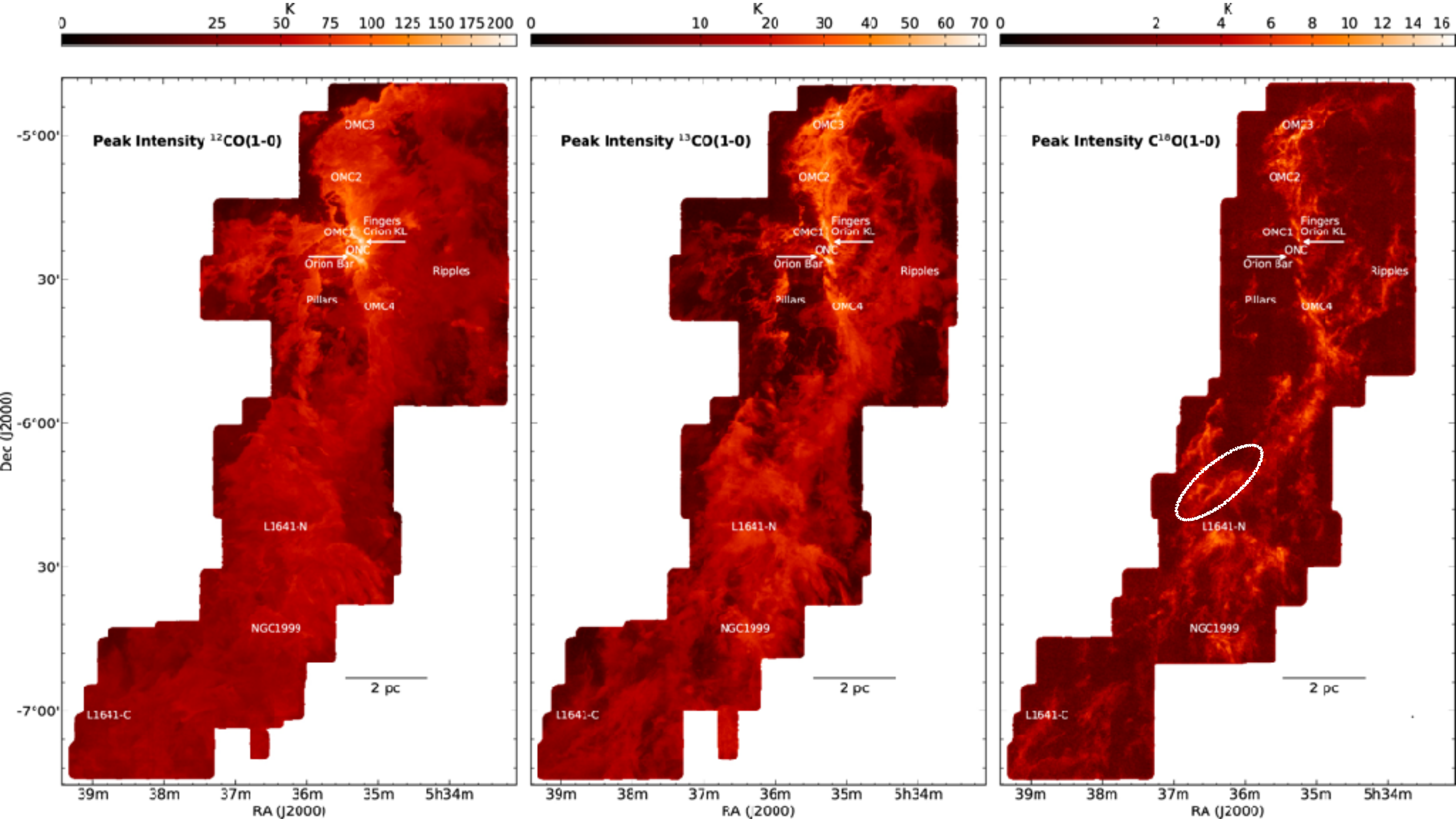
Stutz & Gould (2016)

An Interesting Case: The Stick Filament
1. isolated, straight, very young



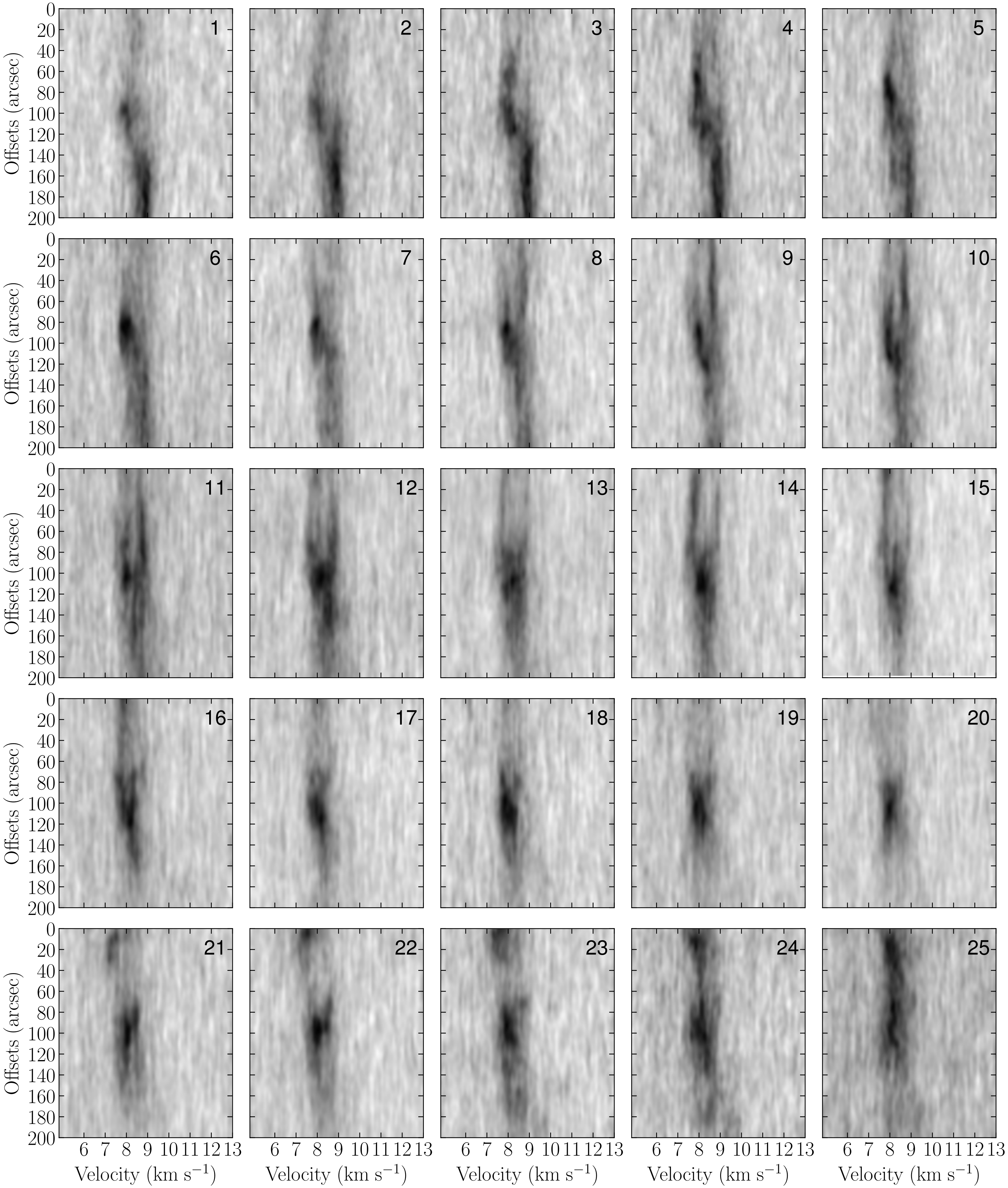
colliding flows? turbulent shocks? magnetic fields?

Coherent in molecular line PPV cube

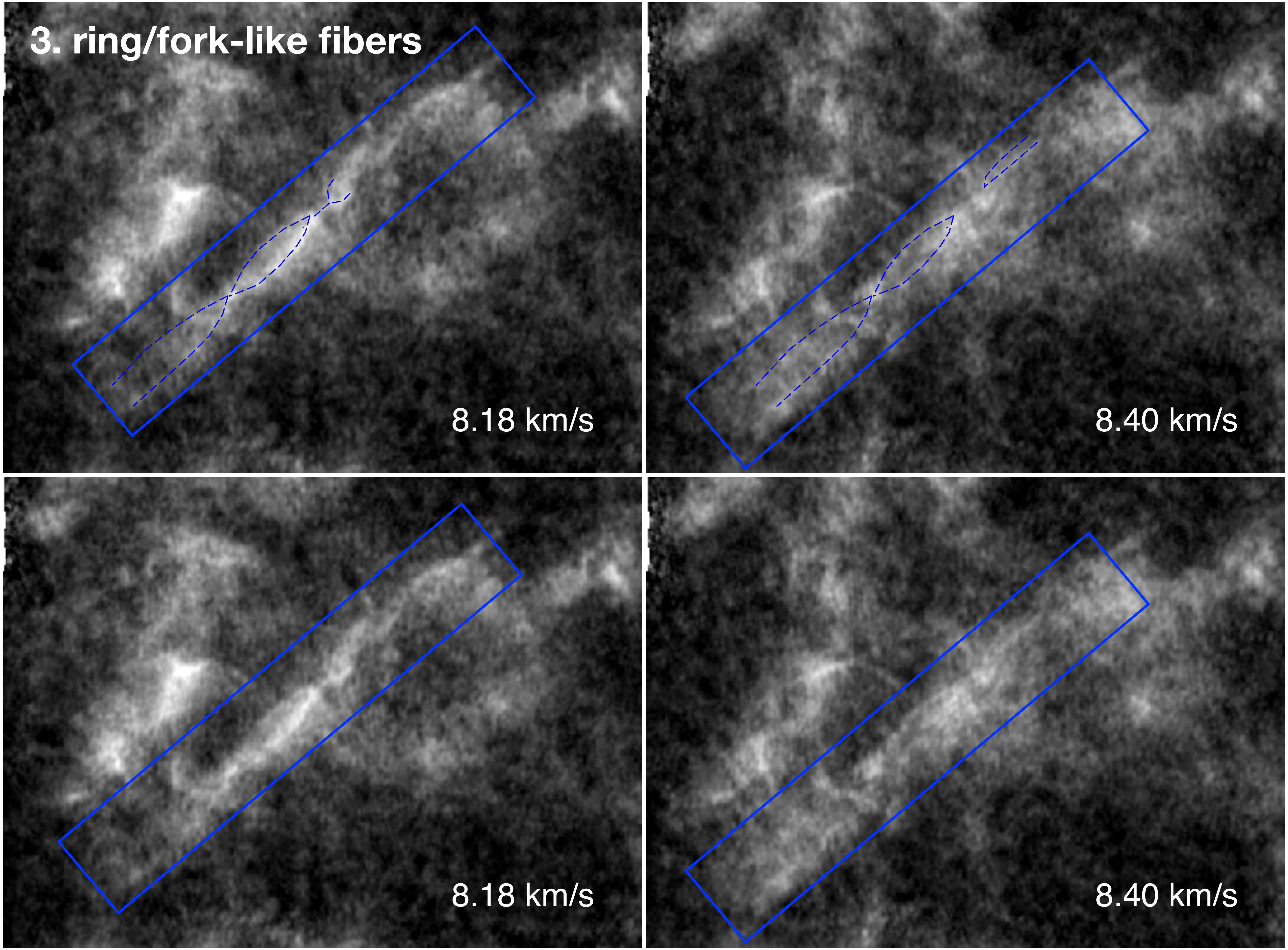


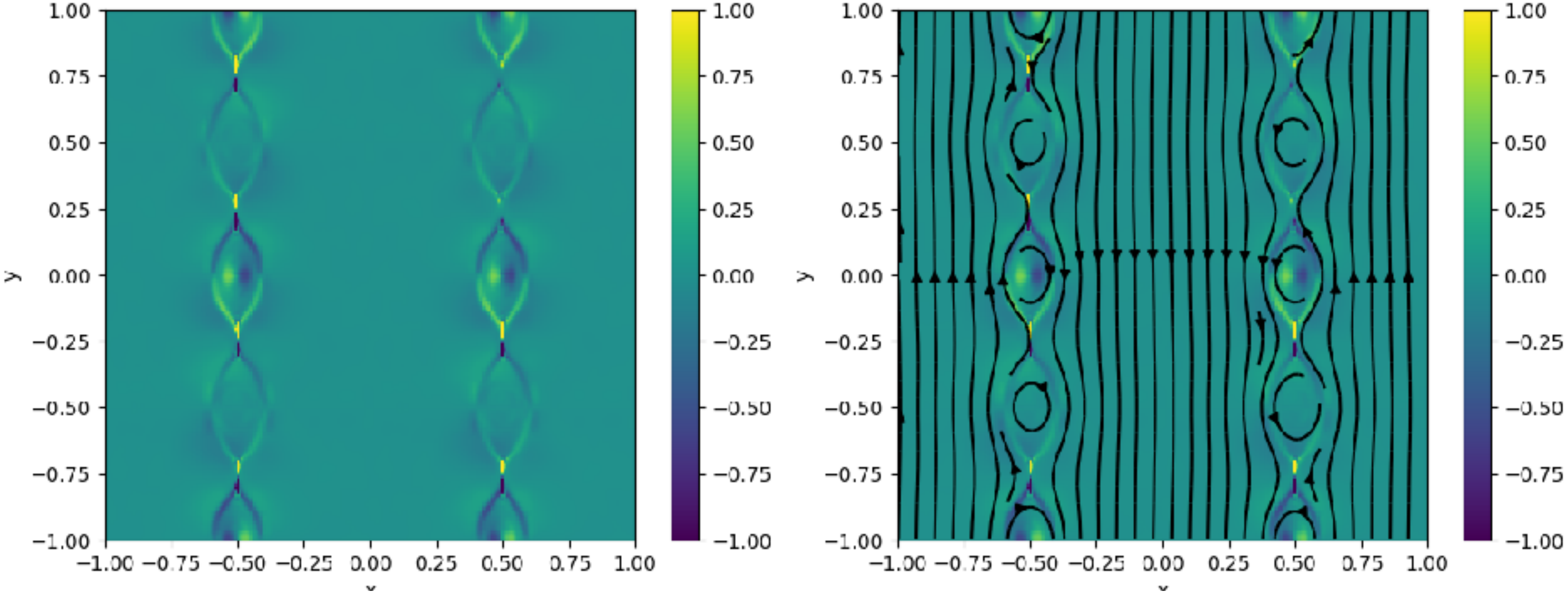
The CARMA-NRO Orion Survey (Kong et al. 2018)

2. A critical feature in C^{18}O(1-0) kinematics: two velocity components



CARMA-NRO Orion Survey, Kong et al. (2018)


3. ring/fork-like fibers
8.18 km/s
8.40 km/s
8.18 km/s
8.40 km/s



Magnetic Reconnection

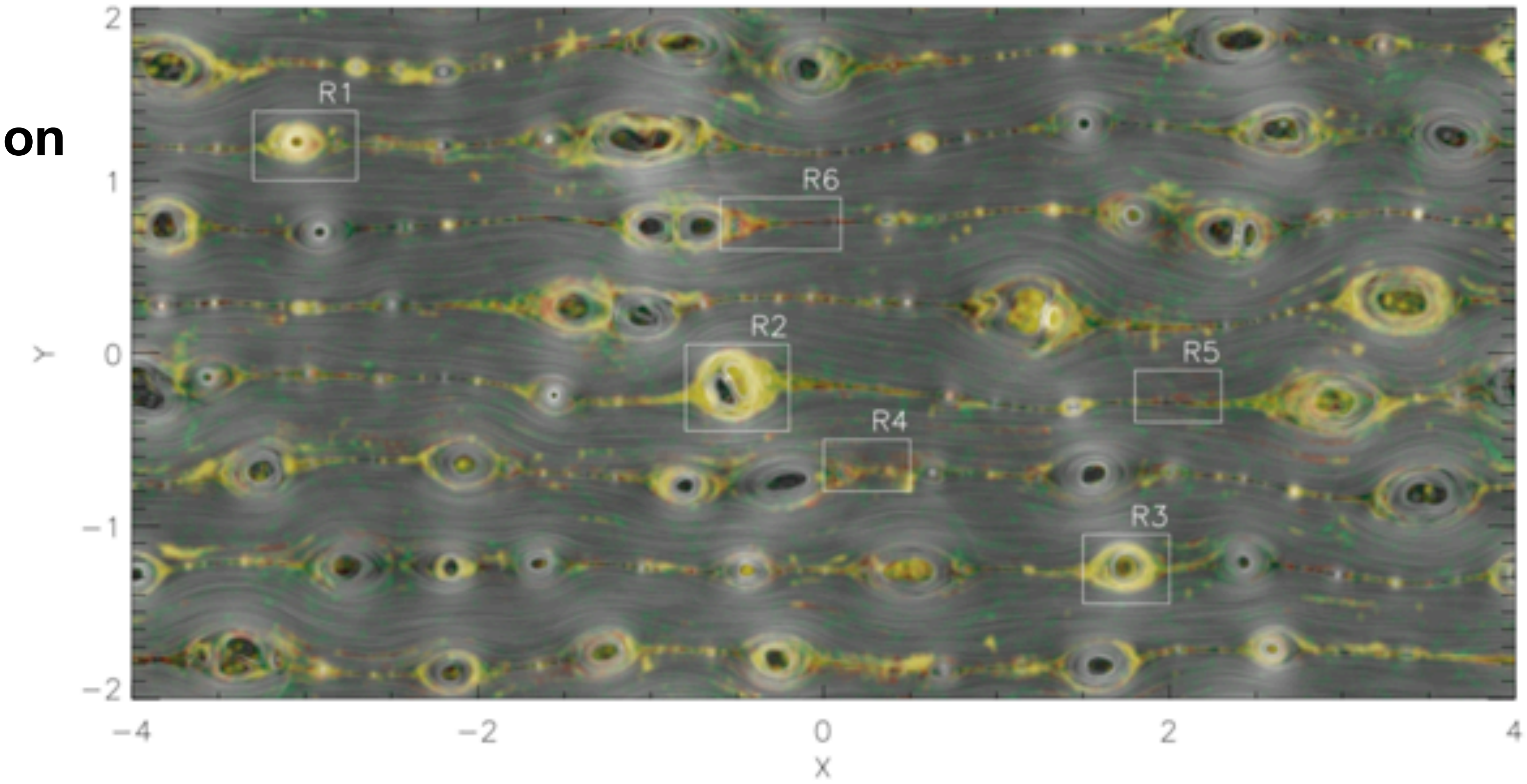


Figure 1. Topology of the magnetic field represented as the gray texture with semitransparent color maps representing locations where the parallel and perpendicular particle velocity components are accelerated for a 2D model with $B_z = 0.0$ at time 6.0 in the code units. The red and green colors correspond to regions where either parallel or perpendicular acceleration occurs, respectively, while the yellow color shows locations where both types of acceleration occur. The parallel component increases in the contracting islands and in the current sheets as well, while the perpendicular component increases mostly in the regions between current sheets. White boxes show regions that are more carefully analyzed in this paper. The simulation was performed with the resolution 8192 × 4096. We injected 10,000 test particles in this snapshot with the initial thermal distribution with a temperature corresponding to the sound speed of the MHD model.

Kowal et al. (2011)

Heiles (1997)

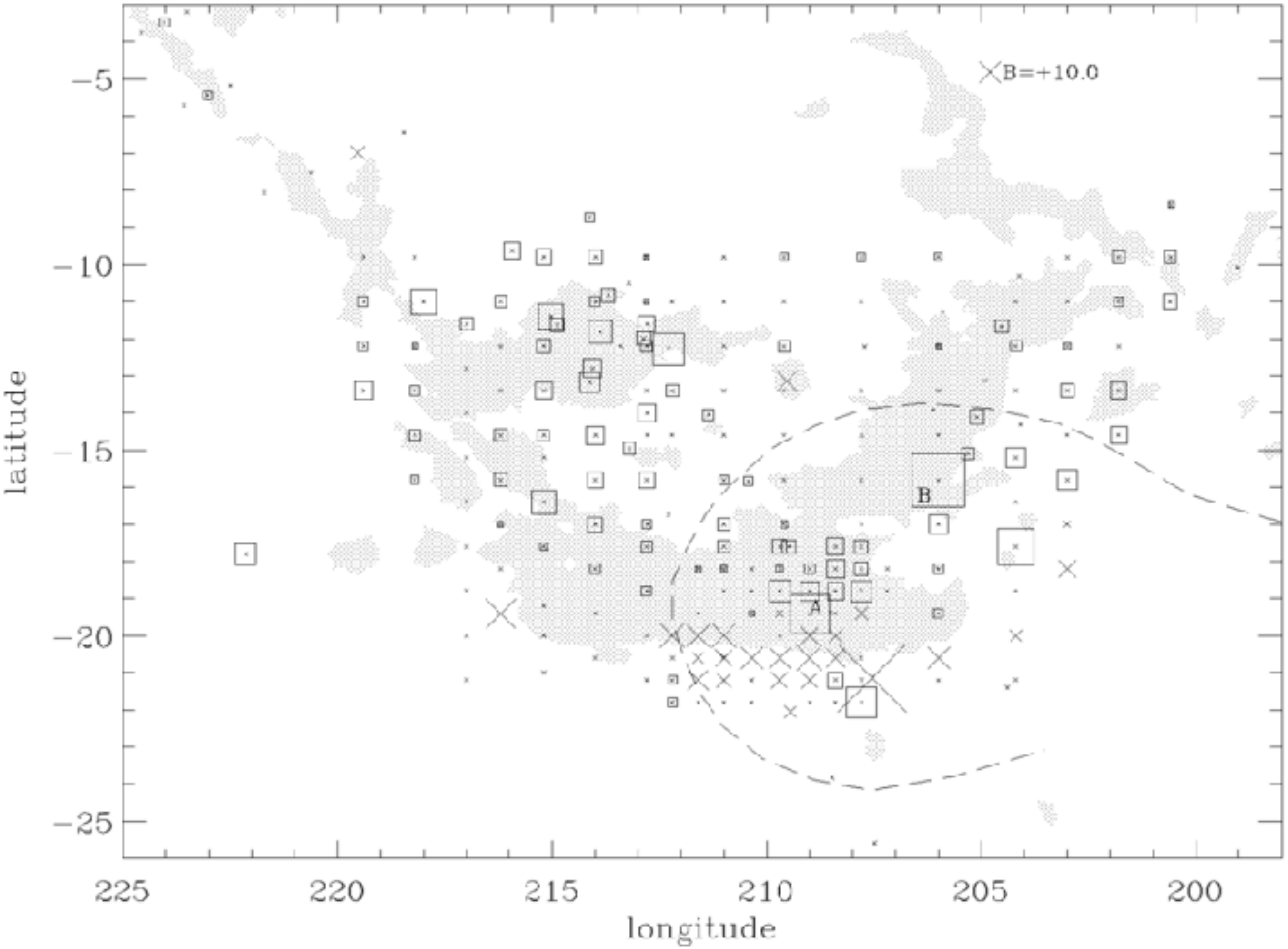


FIG. 15.—Map of Zeeman-splitting detections $B_{\parallel}$. Positive fields are represented by crosses, and negative fields by squares; the calibration for a positive field is shown in the upper right. We show only fields for which $\sigma(B) < B_{\parallel}/3$. As in Fig. 4, small crosses show the locations of all 217 positions observed, the stippled area represents the ^{12}CO molecular clouds from MMMT, the dashed line represents Barnard's loop, and the letters A and B show the positions of Orion A and B.

Soler (2019)

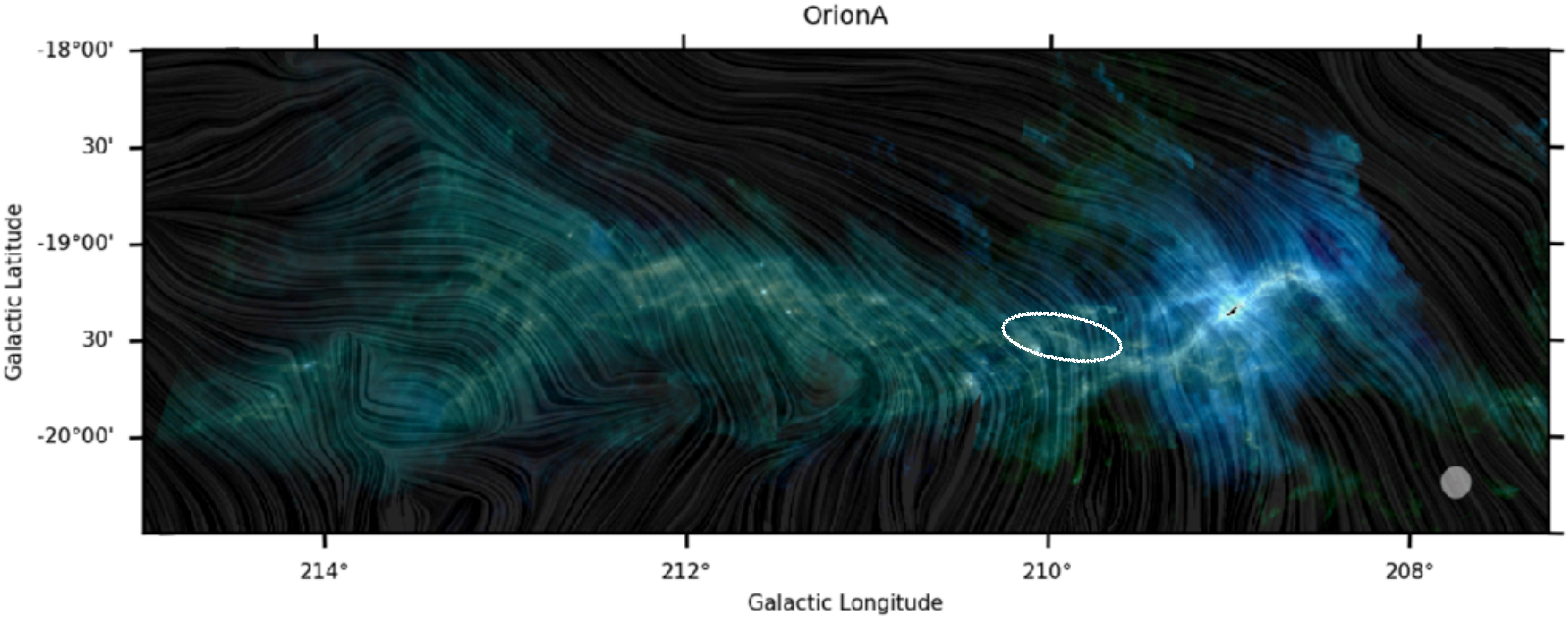
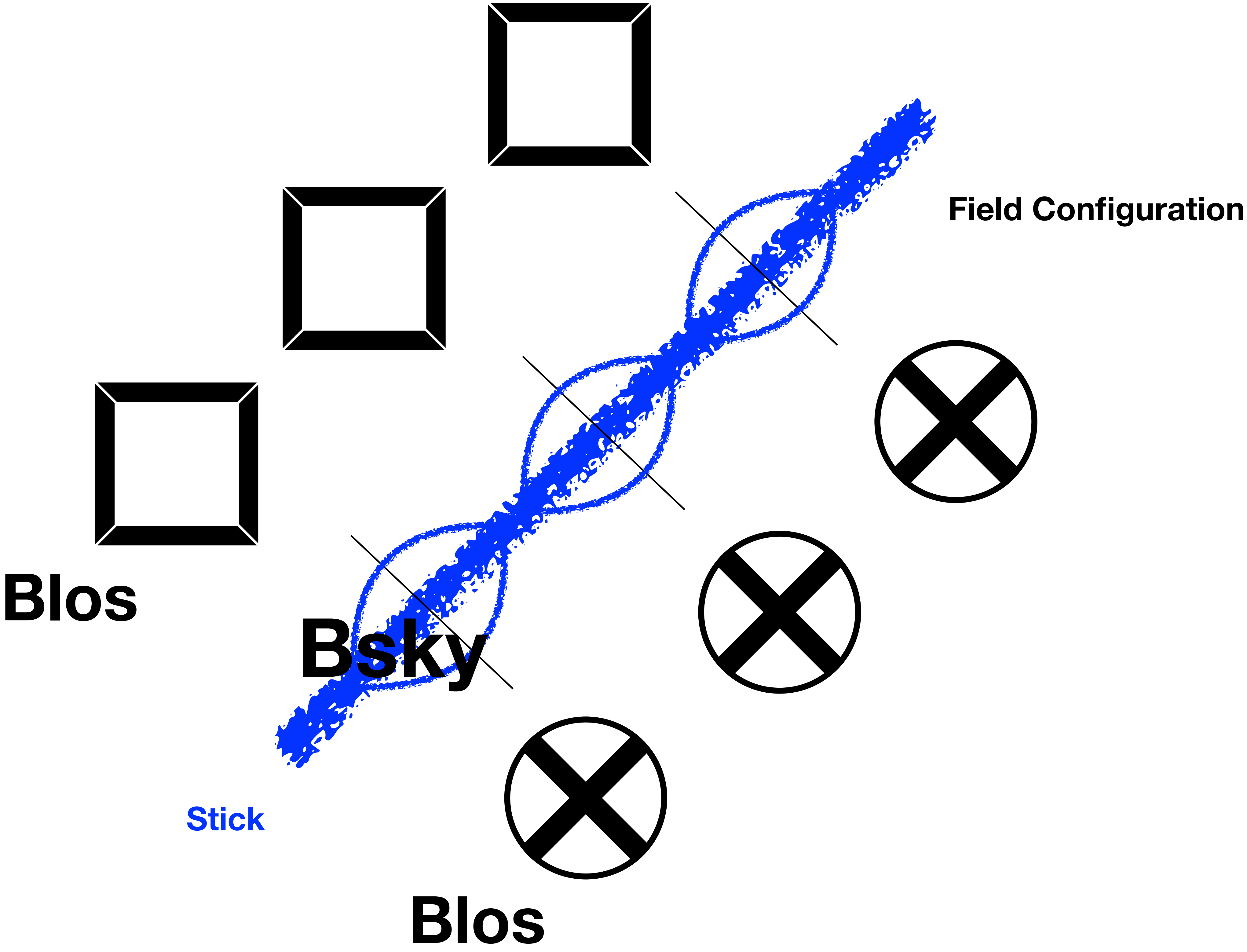
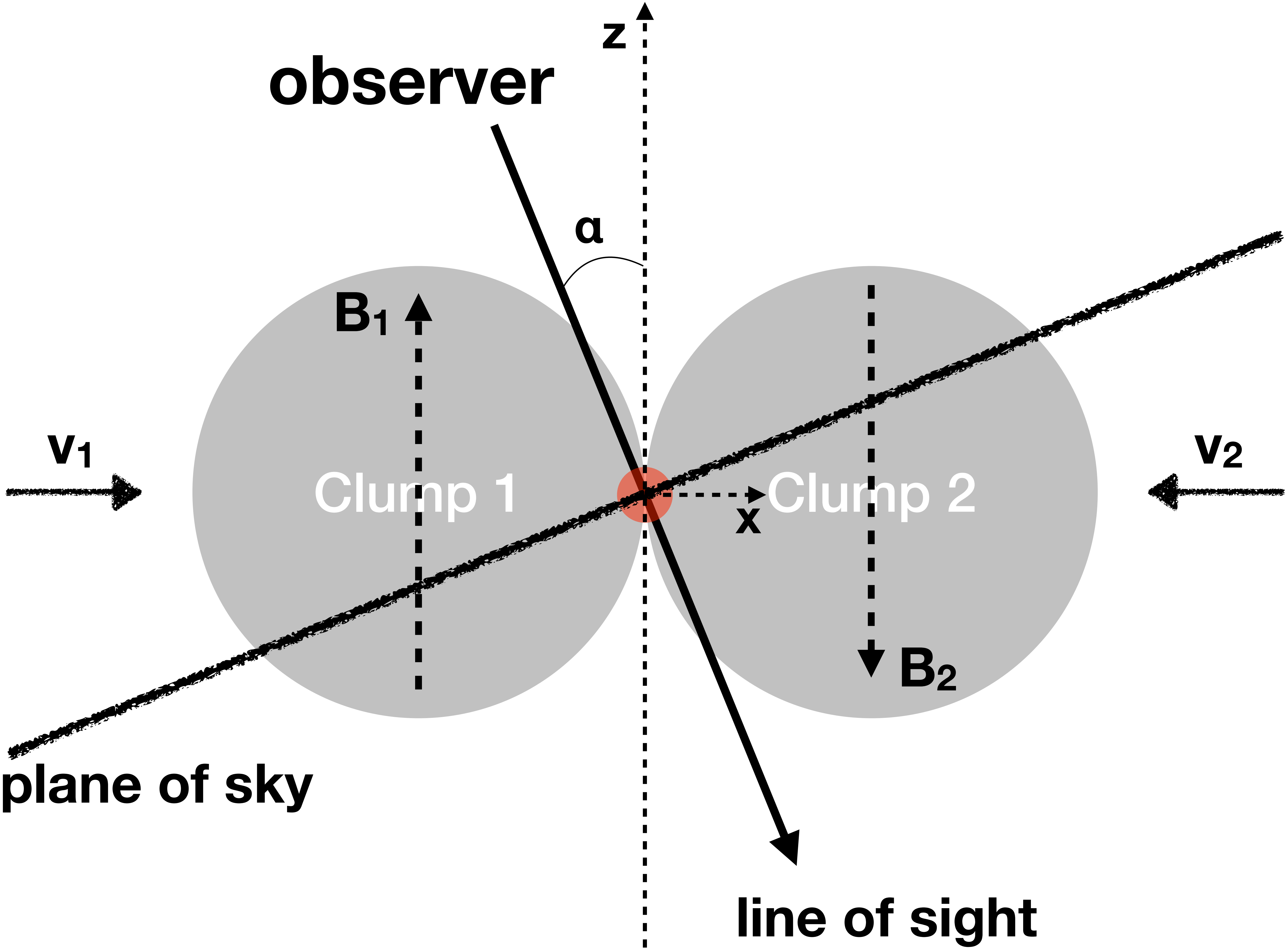
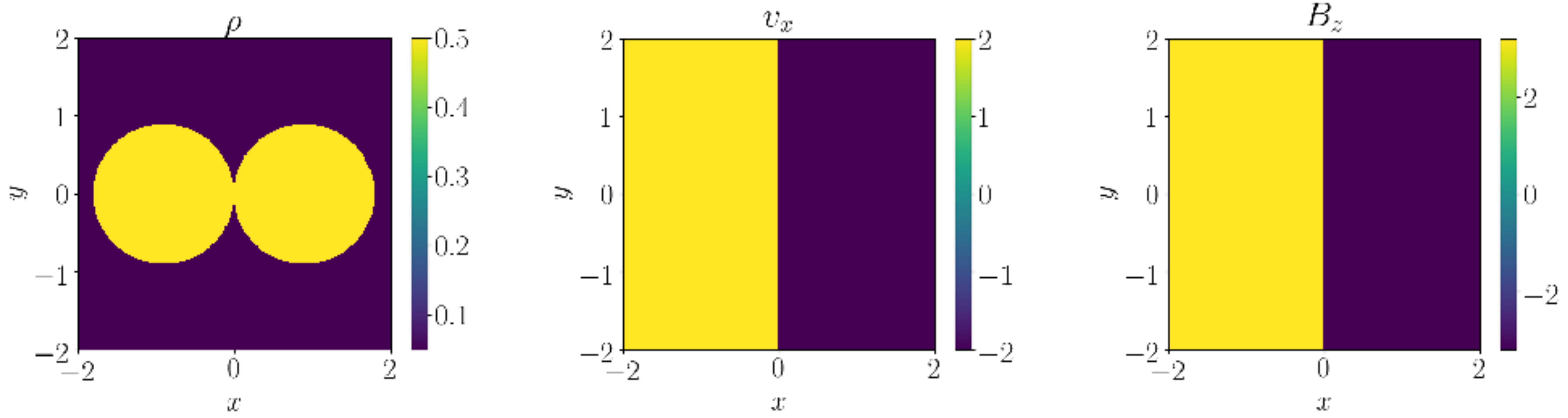


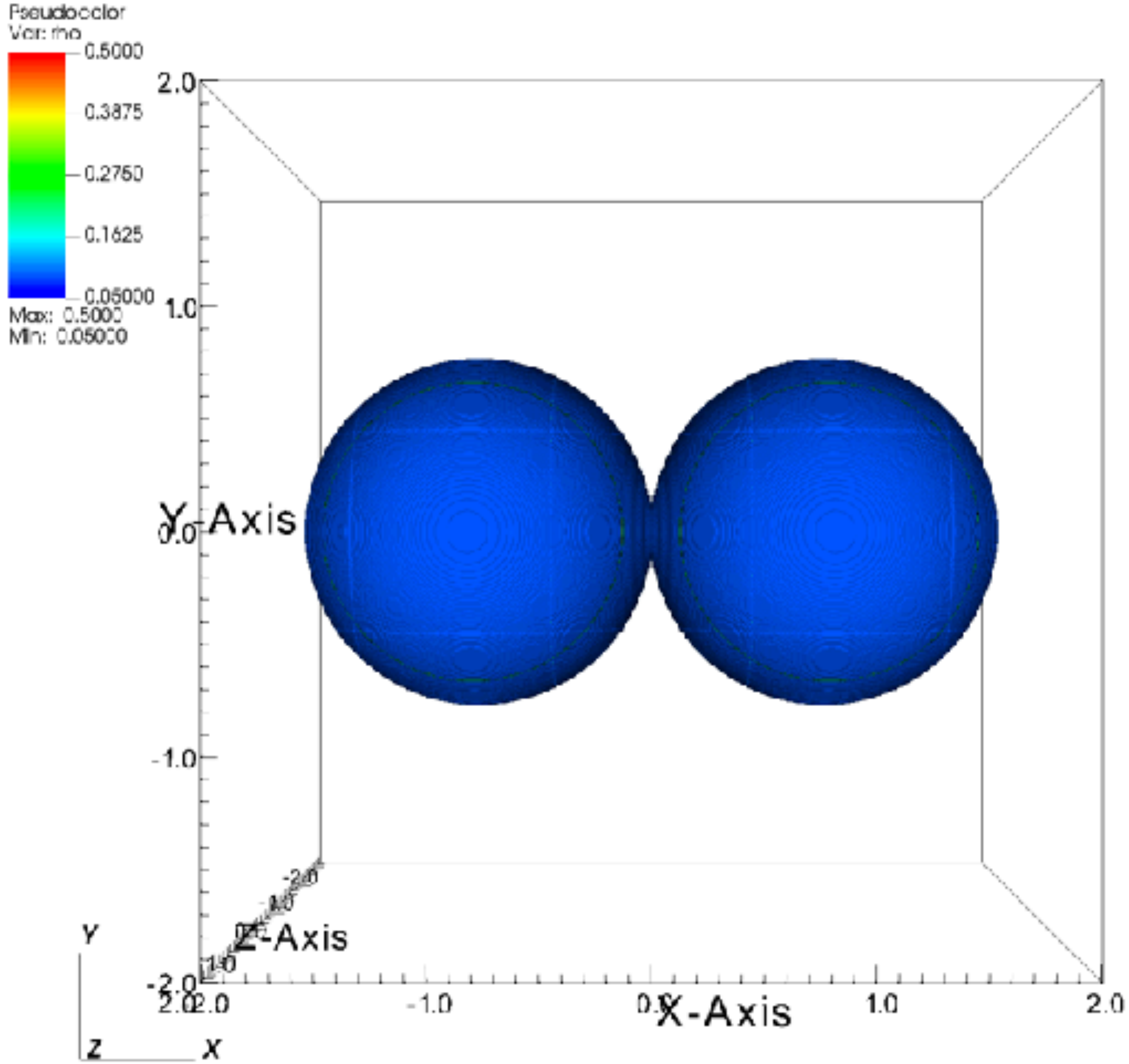
Fig. 9. Emission toward the Orion A region observed by *Herschel* at 160 (blue), 250 (green), and 500 μm (red) and $B_\perp$ (drapery pattern) inferred from the *Planck* 353 GHz polarization observations. The gray disk represents the size of the *Planck* beam. The red dot represents the size of the *Herschel* 500 μm beam.

An isolated, straight, young filament made by cloud-cloud collision with magnetic reconnection?



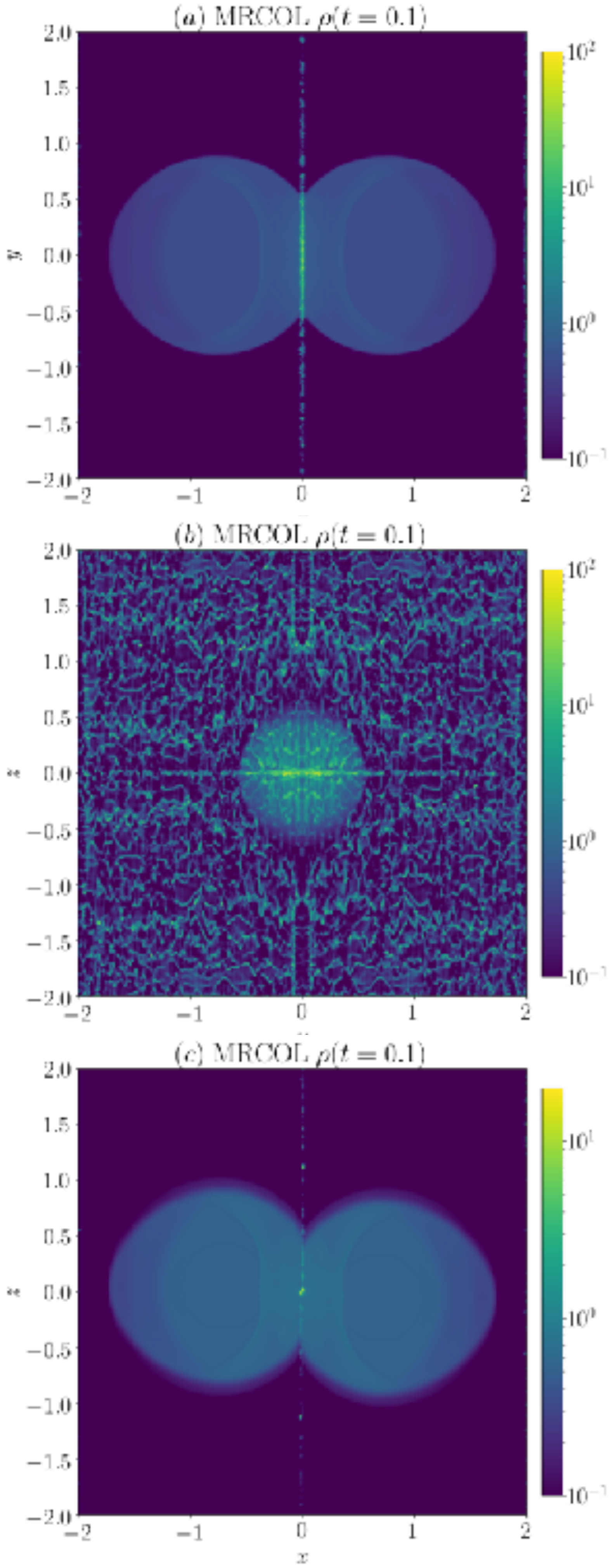

z
observer
α
B_1
v_1
Clump 1
x
Clump 2
v_2
B_2
plane of sky
line of sight





Initial Conditions for MRCOL (fiducial)

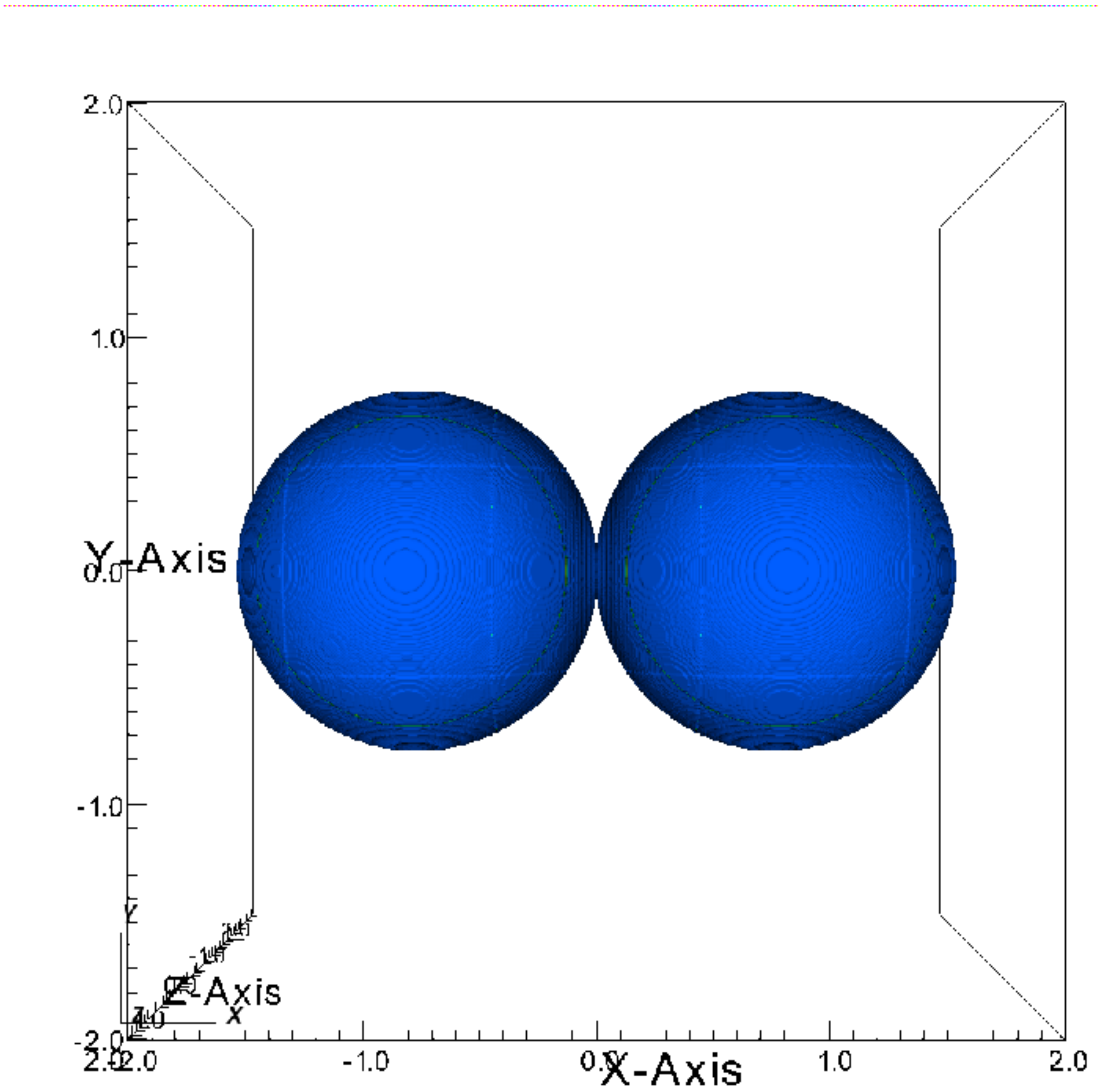
Athena++ (Stone et al. 2020)
512^3 uniform grid
compressible, isothermal, inviscid
magnetohydrodynamics (MHD),
with self-gravity and Ohmic resistivity
periodic boundary conditions
4x4x4 pc^3 computation domain
initial density n_{H2} = 420 cm^{-3}
collision velocity 2 km s^{-1} from obs
temperature 15 K from obs
magnetic field 10 μG from obs

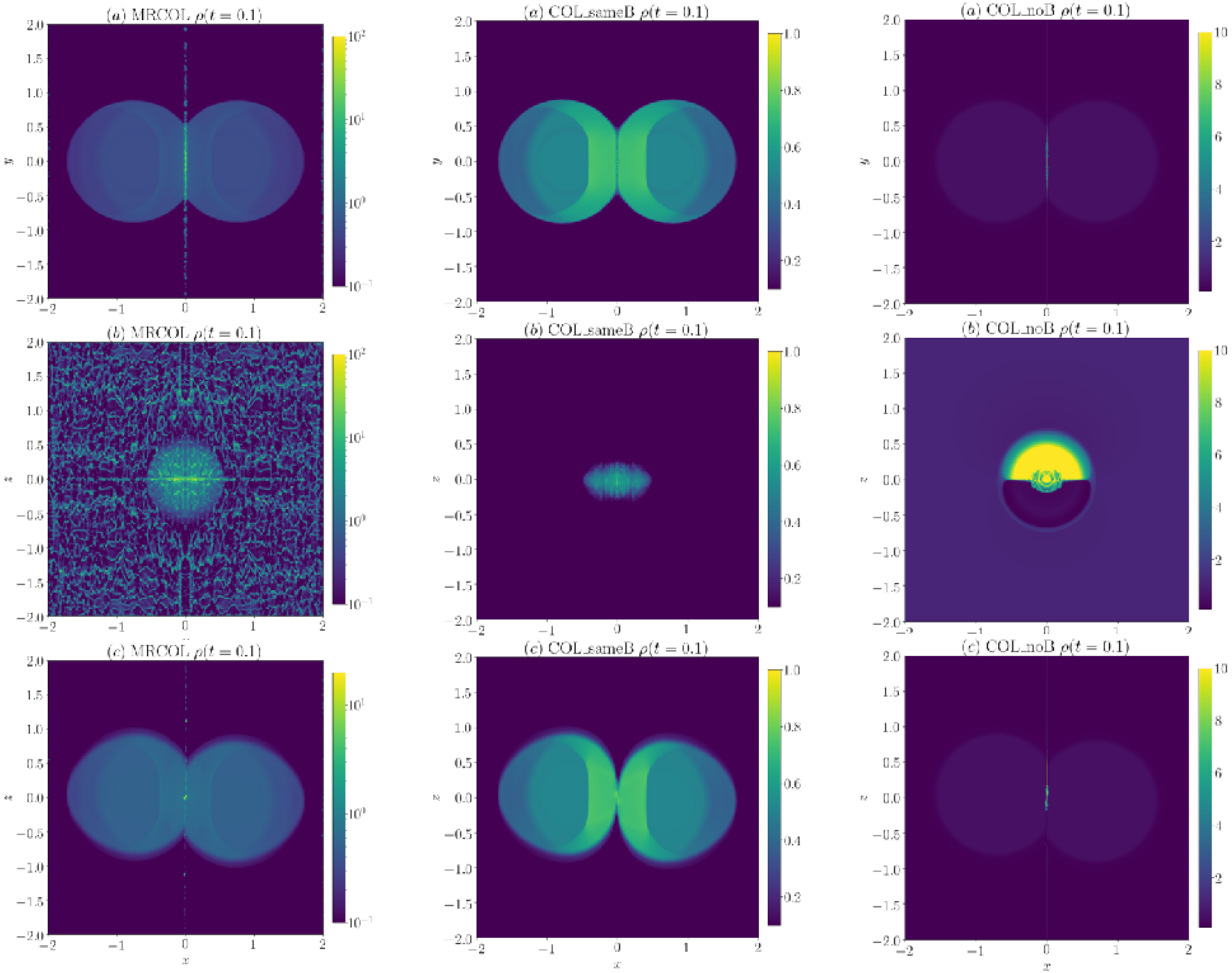


(a) MRCOL $\rho(t = 0.1)$

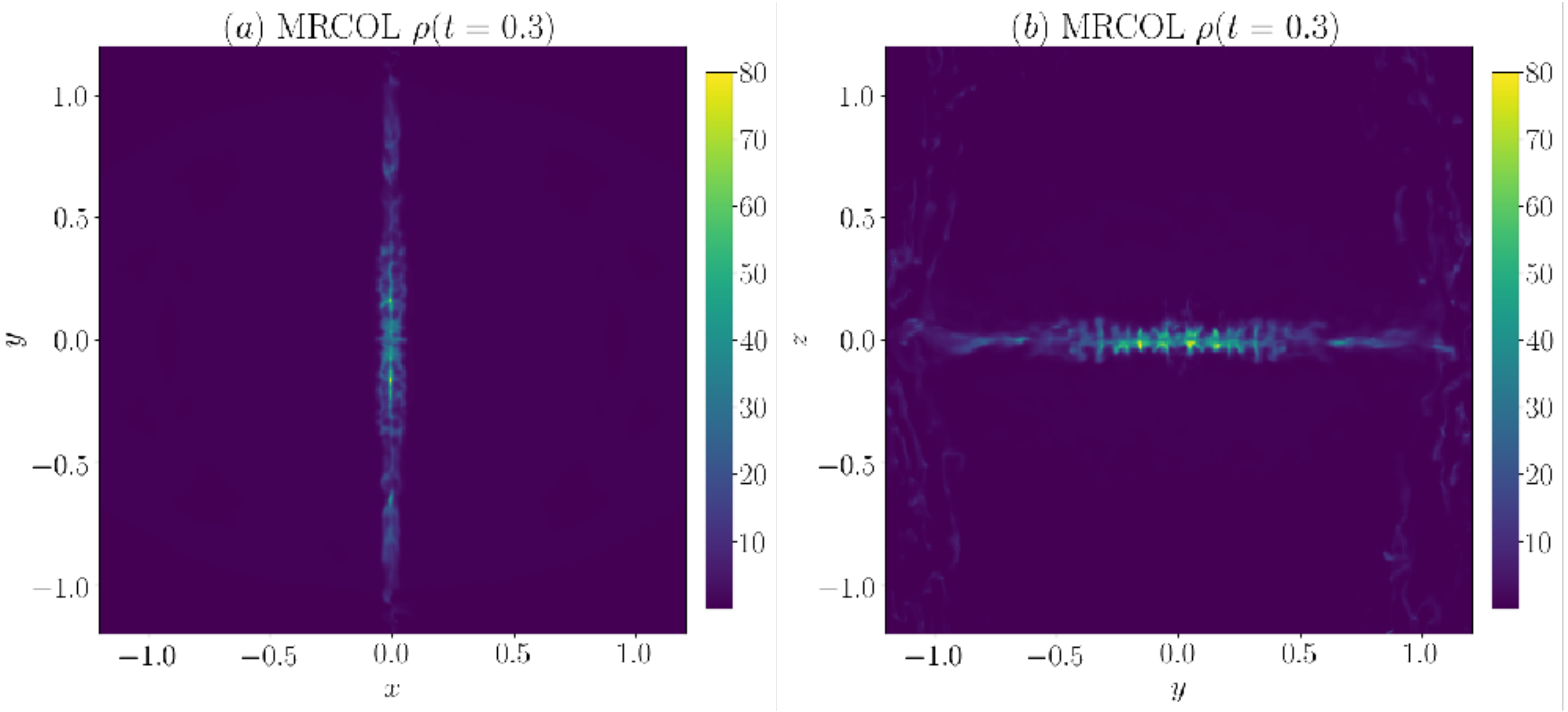
(b) MRCOL $\rho(t = 0.1)$

(c) MRCOL $\rho(t = 0.1)$

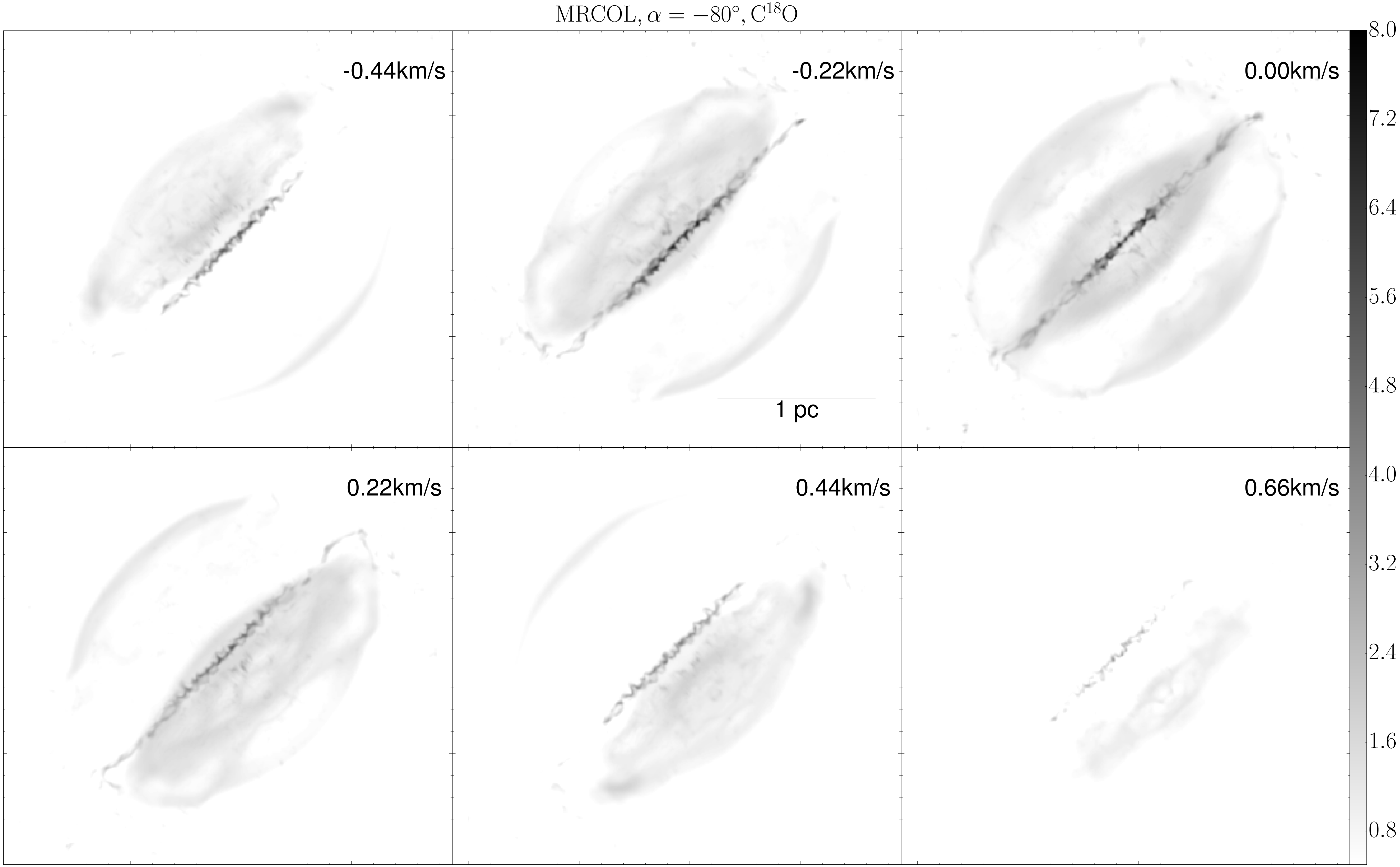



(a) MRCOL $\rho(t = 0.1)$
(a) COL_sameB $\rho(t = 0.1)$
(a) COL_noB $\rho(t = 0.1)$
(b) MRCOL $\rho(t = 0.1)$
(b) COL_sameB $\rho(t = 0.1)$
(b) COL_noB $\rho(t = 0.1)$
(c) MRCOL $\rho(t = 0.1)$
(c) COL_sameB $\rho(t = 0.1)$
(c) COL_noB $\rho(t = 0.1)$
x
y
z
−2.0 −1.5 −1.0 −0.5 0.0 0.5 1.0 1.5 2.0
−2 −1 0 1 2
10^{-1} 10^{0} 10^{1} 10^{2}
0.2 0.4 0.6 0.8 1.0
2 4 6 8 10

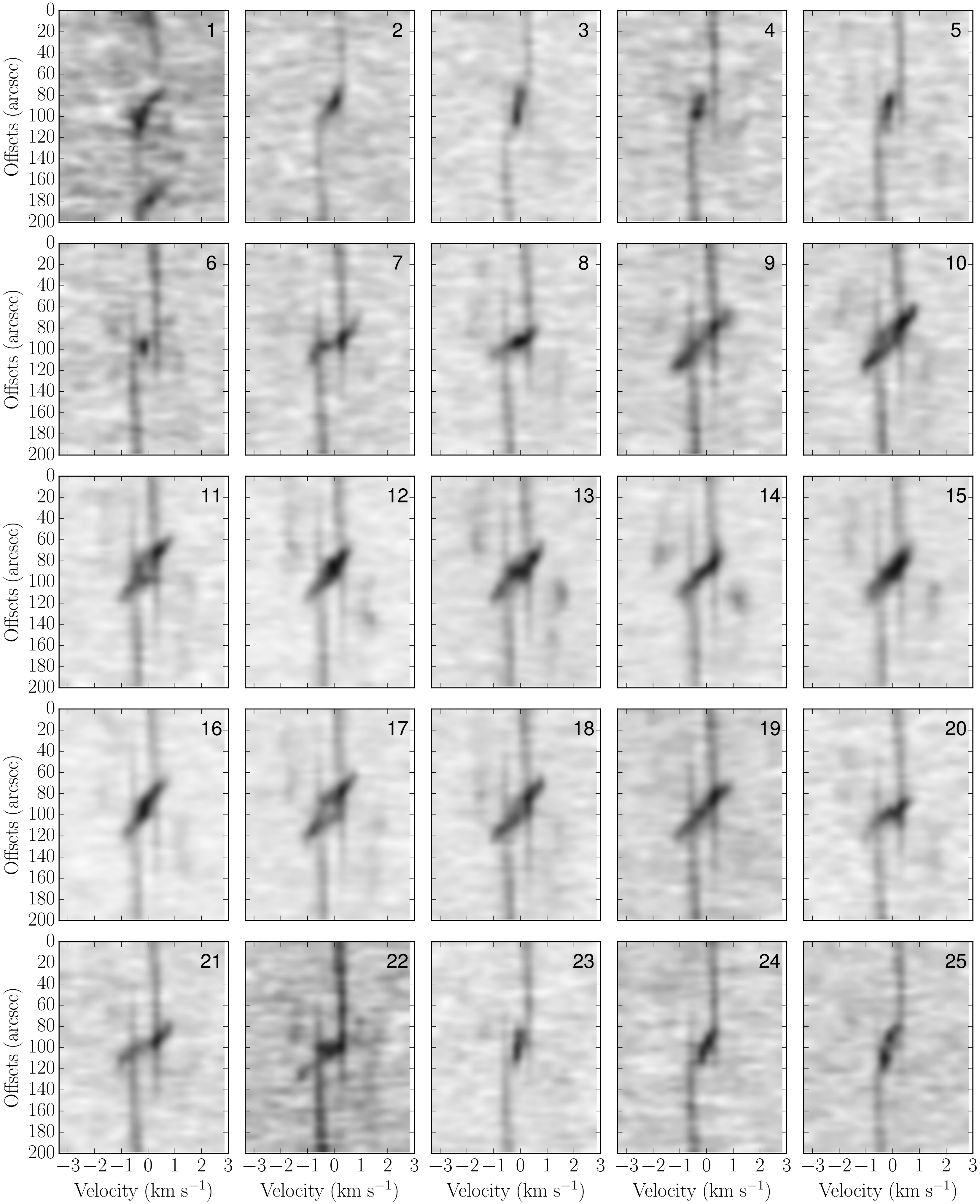
MRCOL at t=0.6 Myr



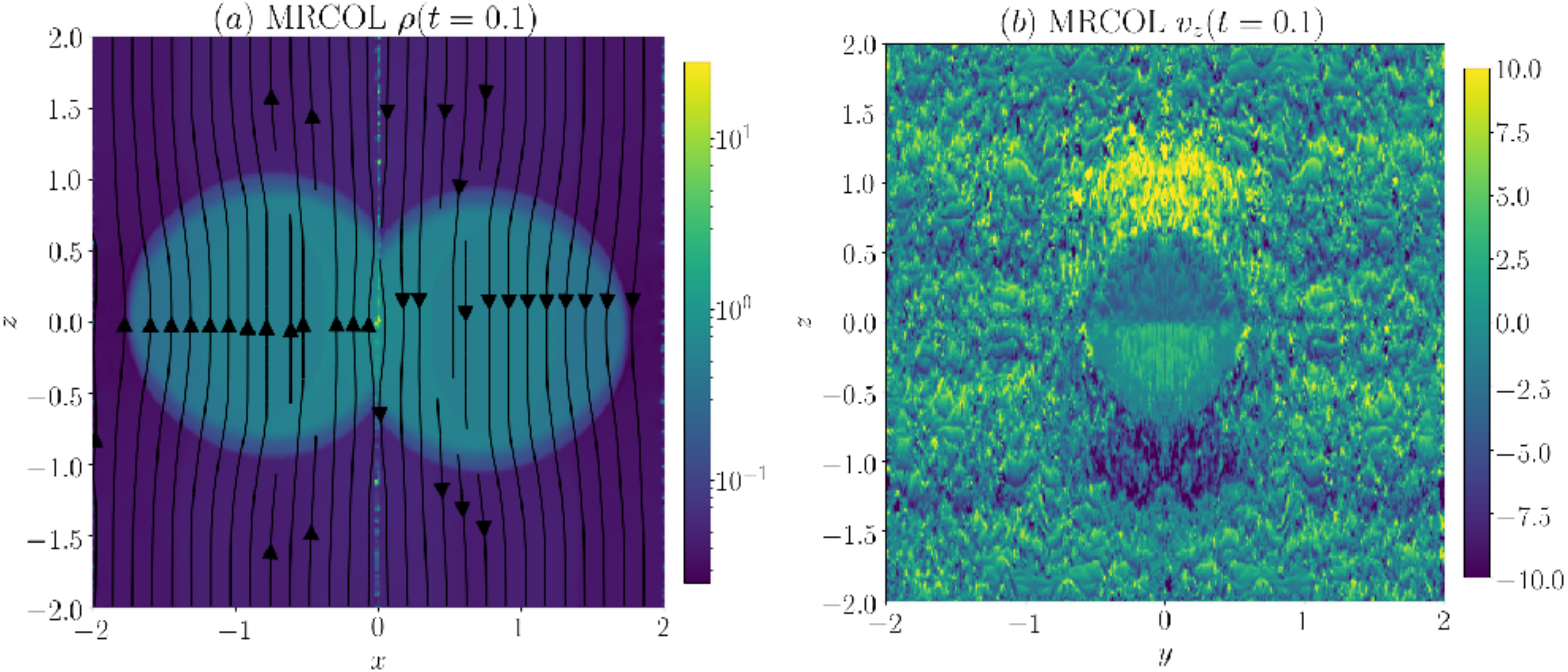
Radiative Transfer: SimLine3D (Ossenkopf 2002)



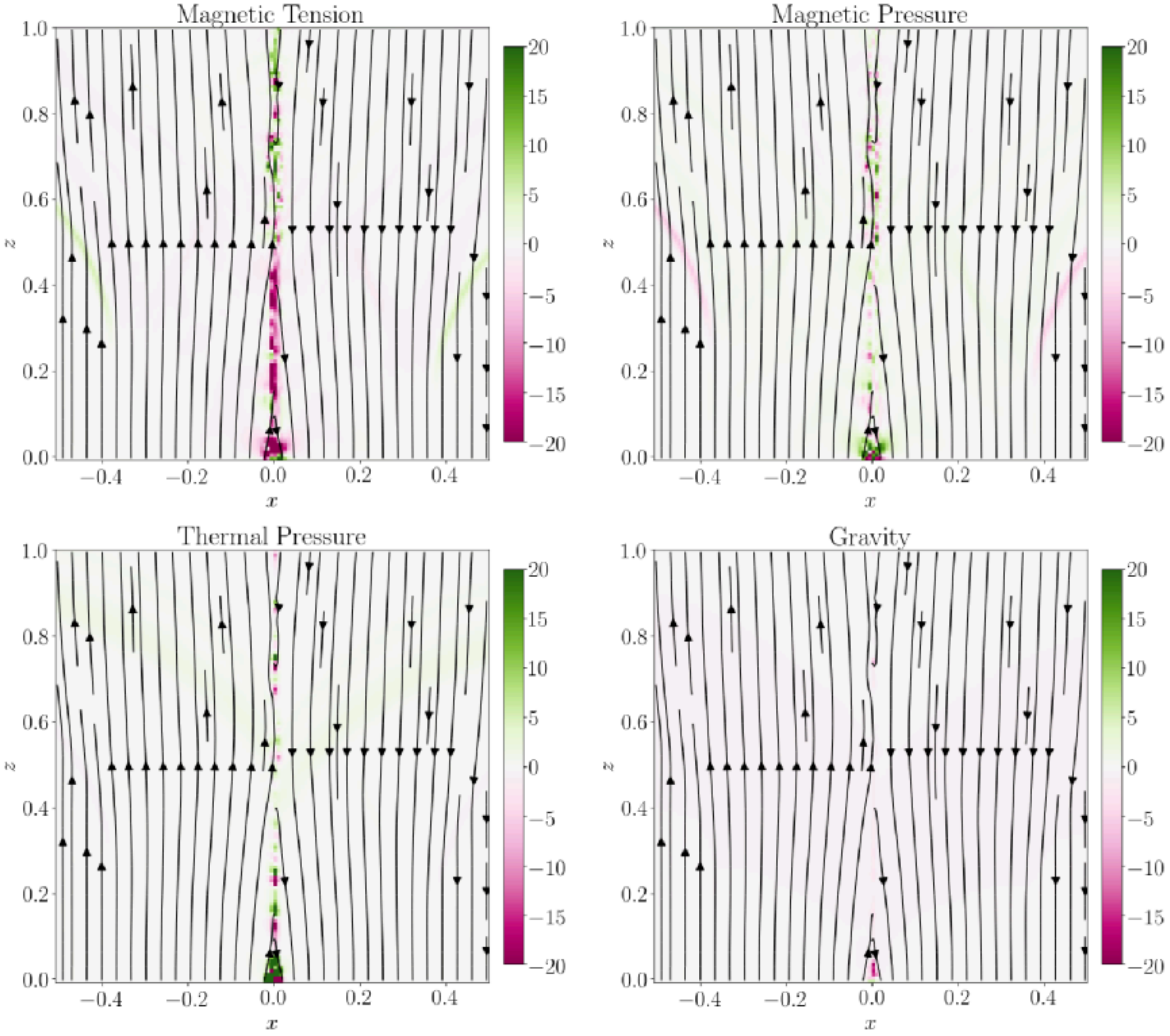
PV-diagrams for MRCOL

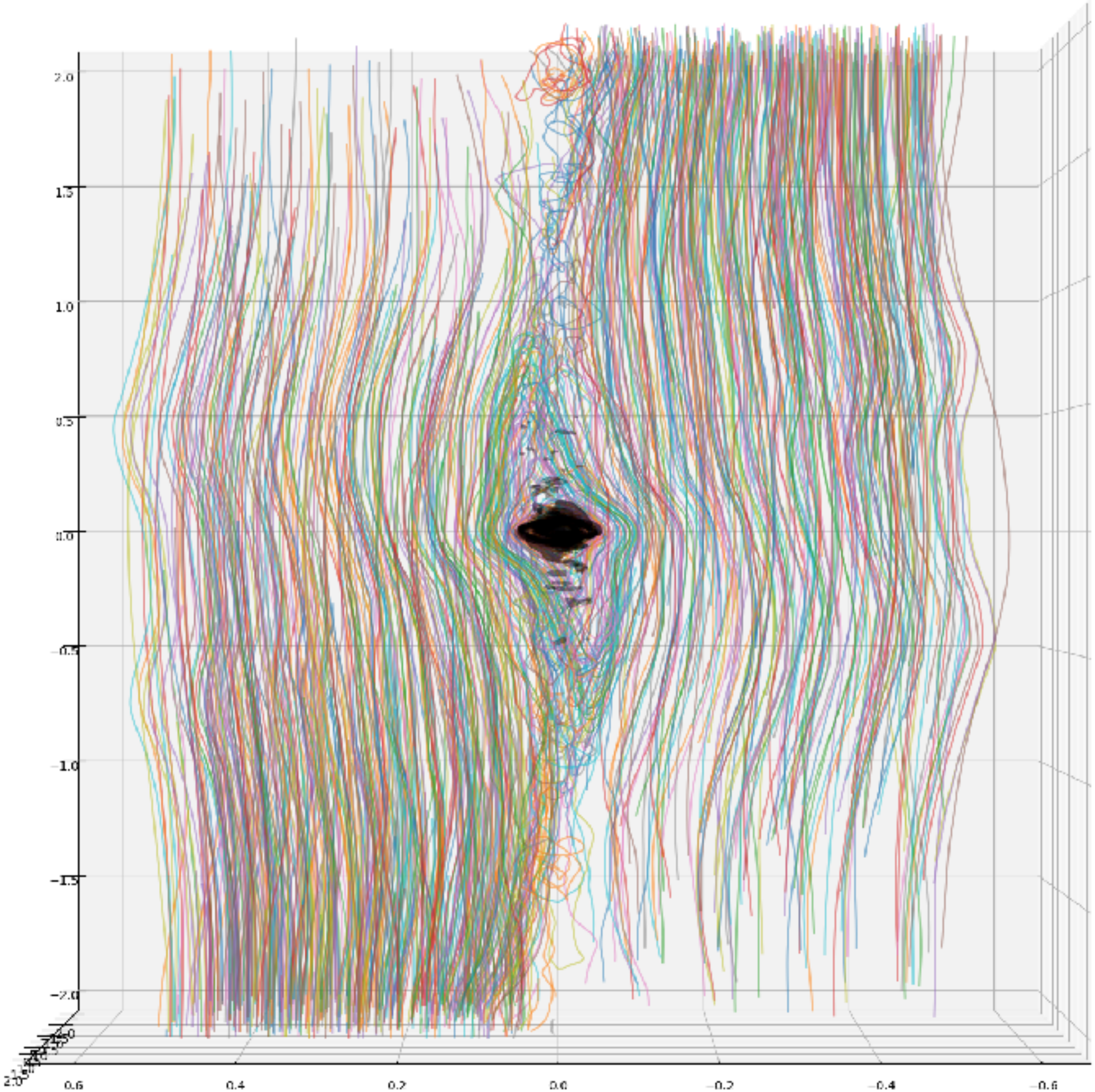


Physical Origin

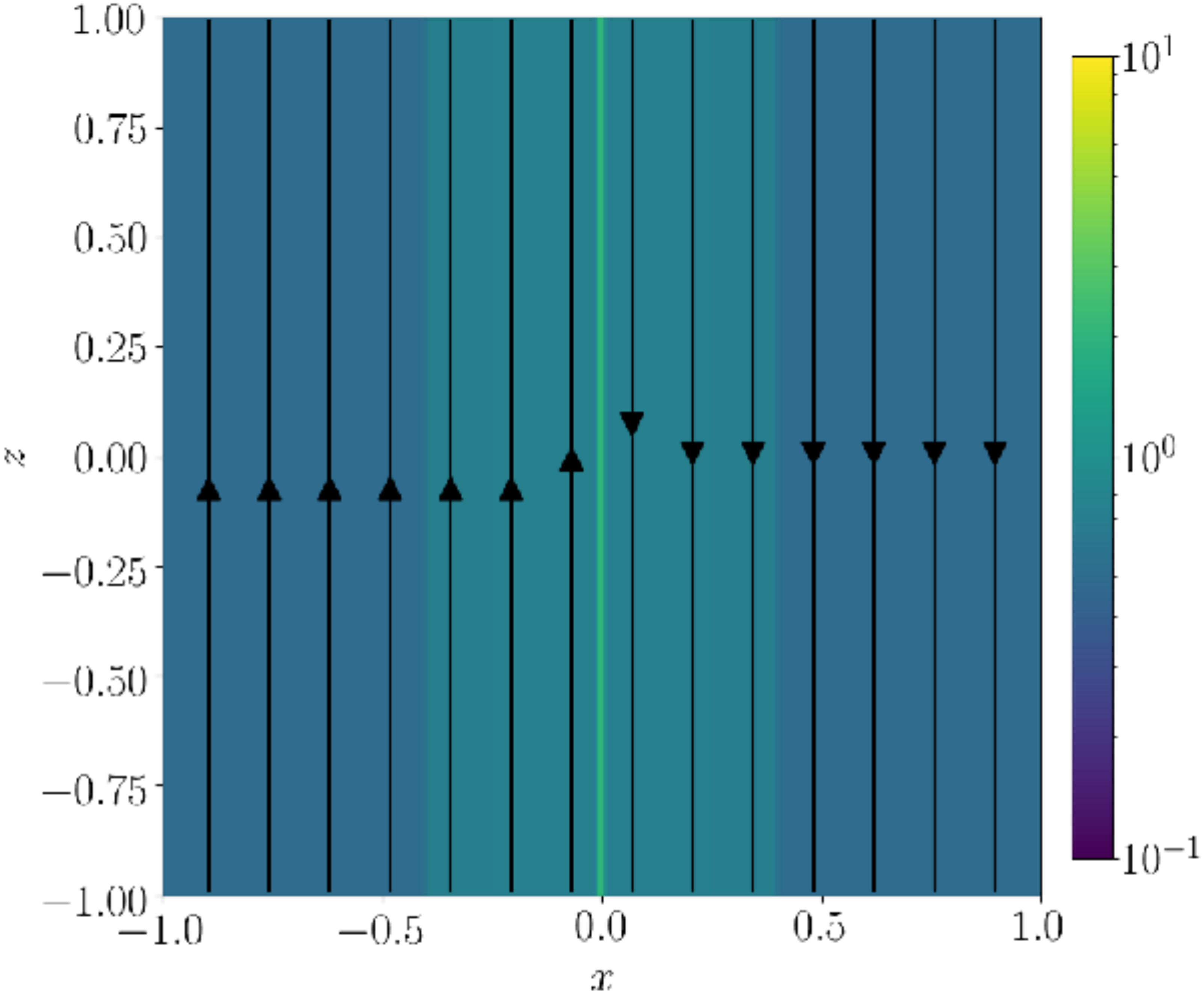


$$-\nabla P - \nabla\left(\frac{B^2}{8\pi}\right) + (\mathbf{B}\cdot\nabla)\frac{\mathbf{B}}{4\pi} - \rho\nabla\phi.$$

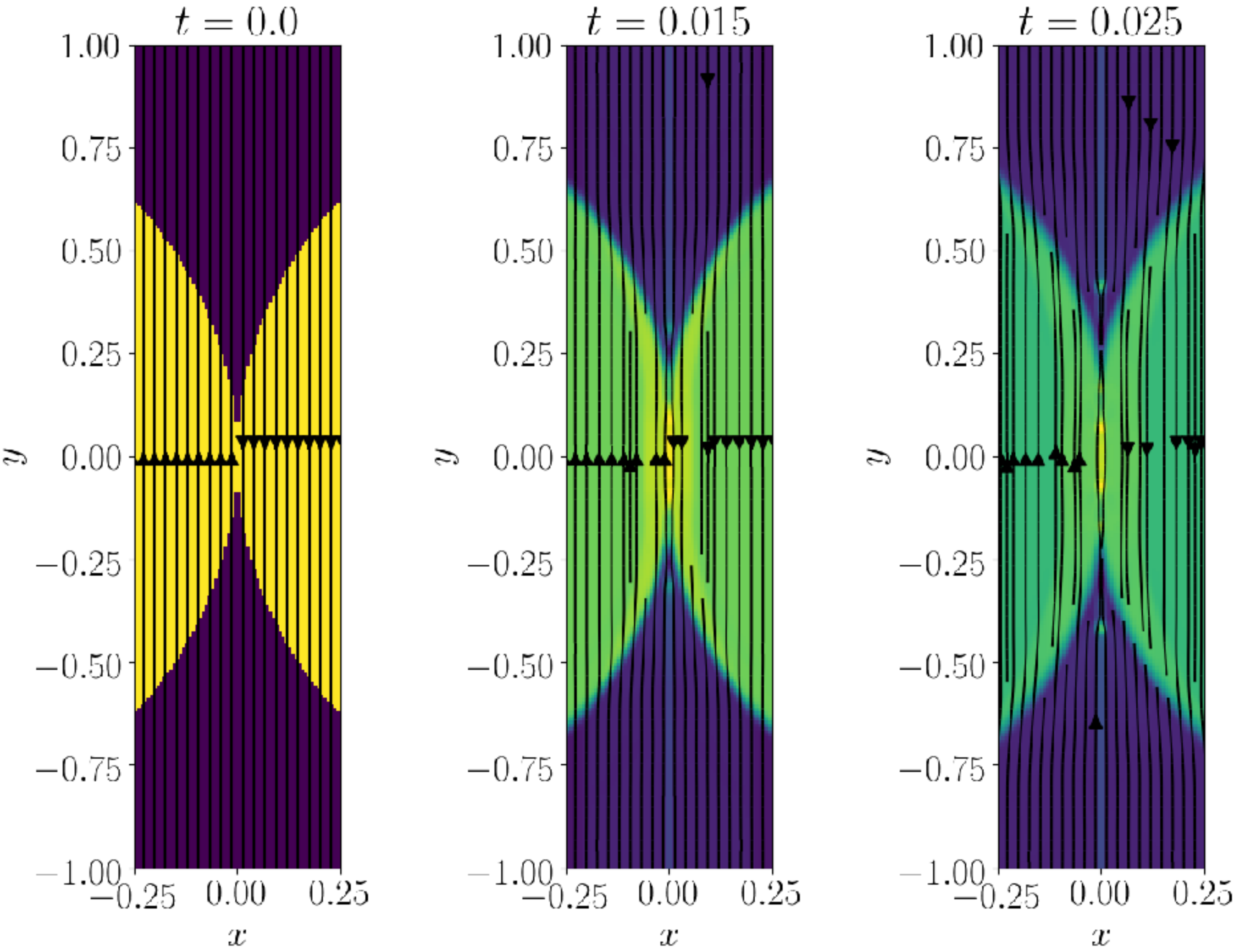

Magnetic Tension
Magnetic Pressure
Thermal Pressure
Gravity
z
x
1.0
0.8
0.6
0.4
0.2
0.0
−0.4
−0.2
0.0
0.2
0.4
20
15
10
5
0
−5
−10
−15
−20

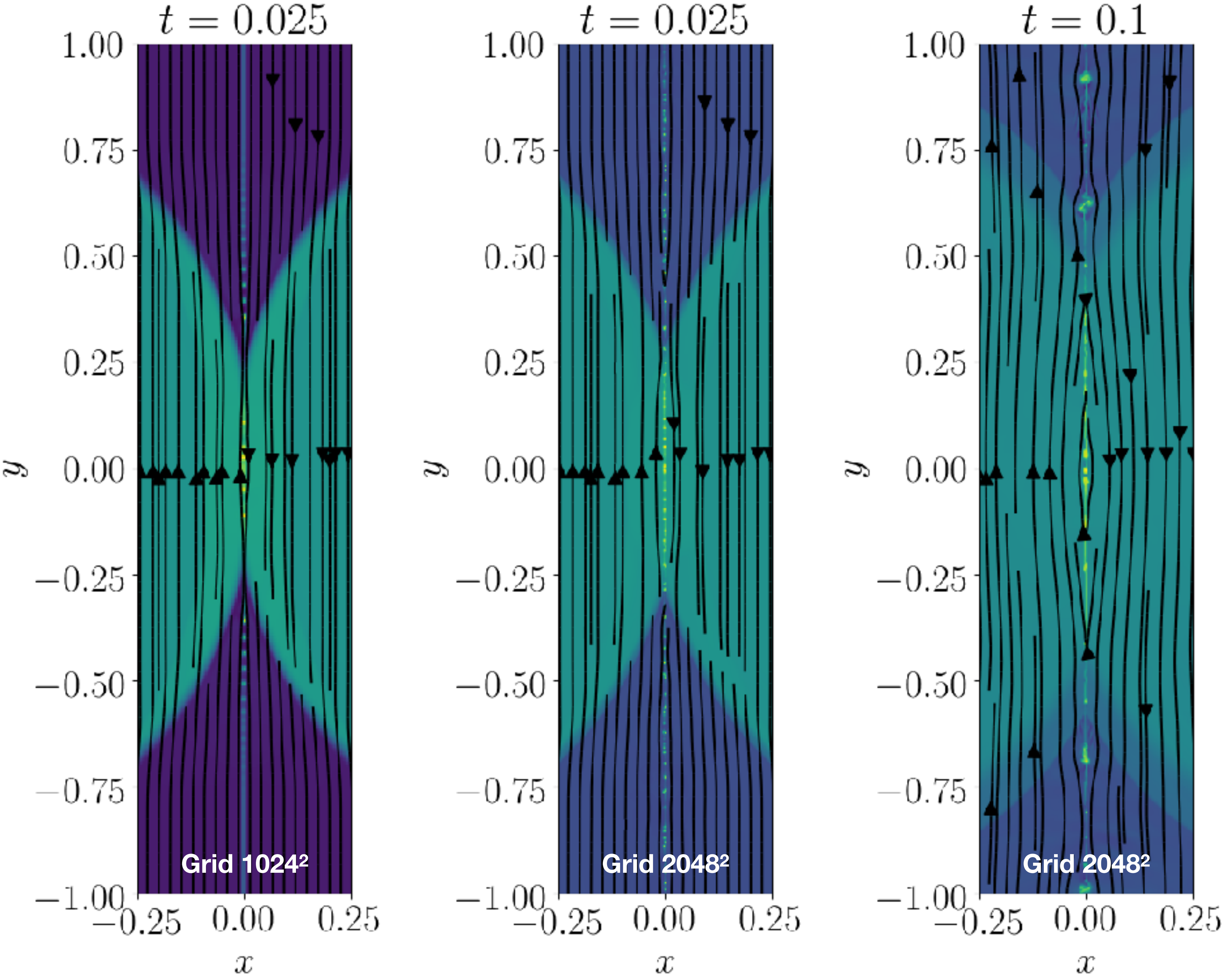

2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6

Uniform density on both sides
Collision does not trigger CMR

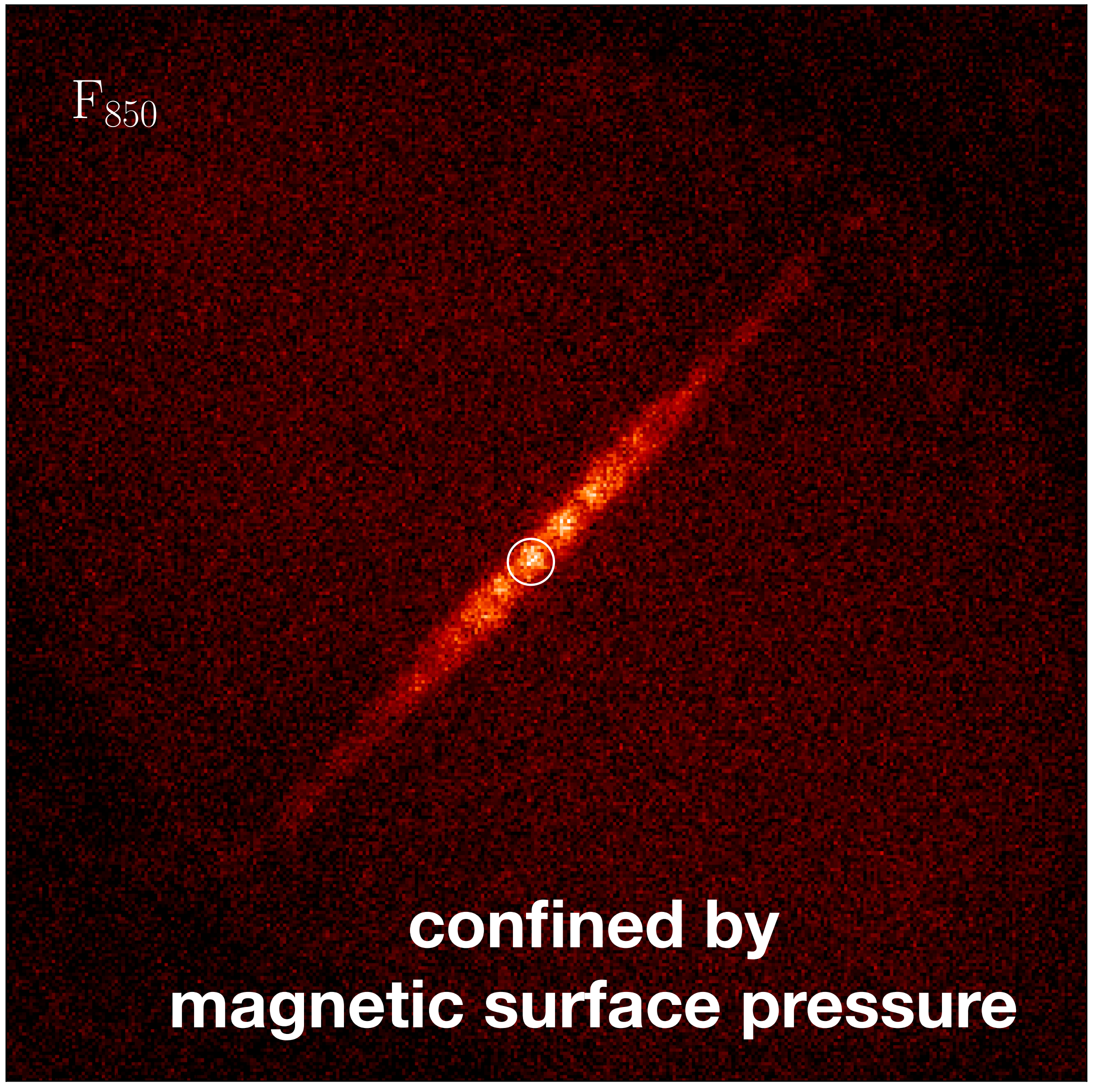


Collision-induced Magnetic Reconnection (CMR)



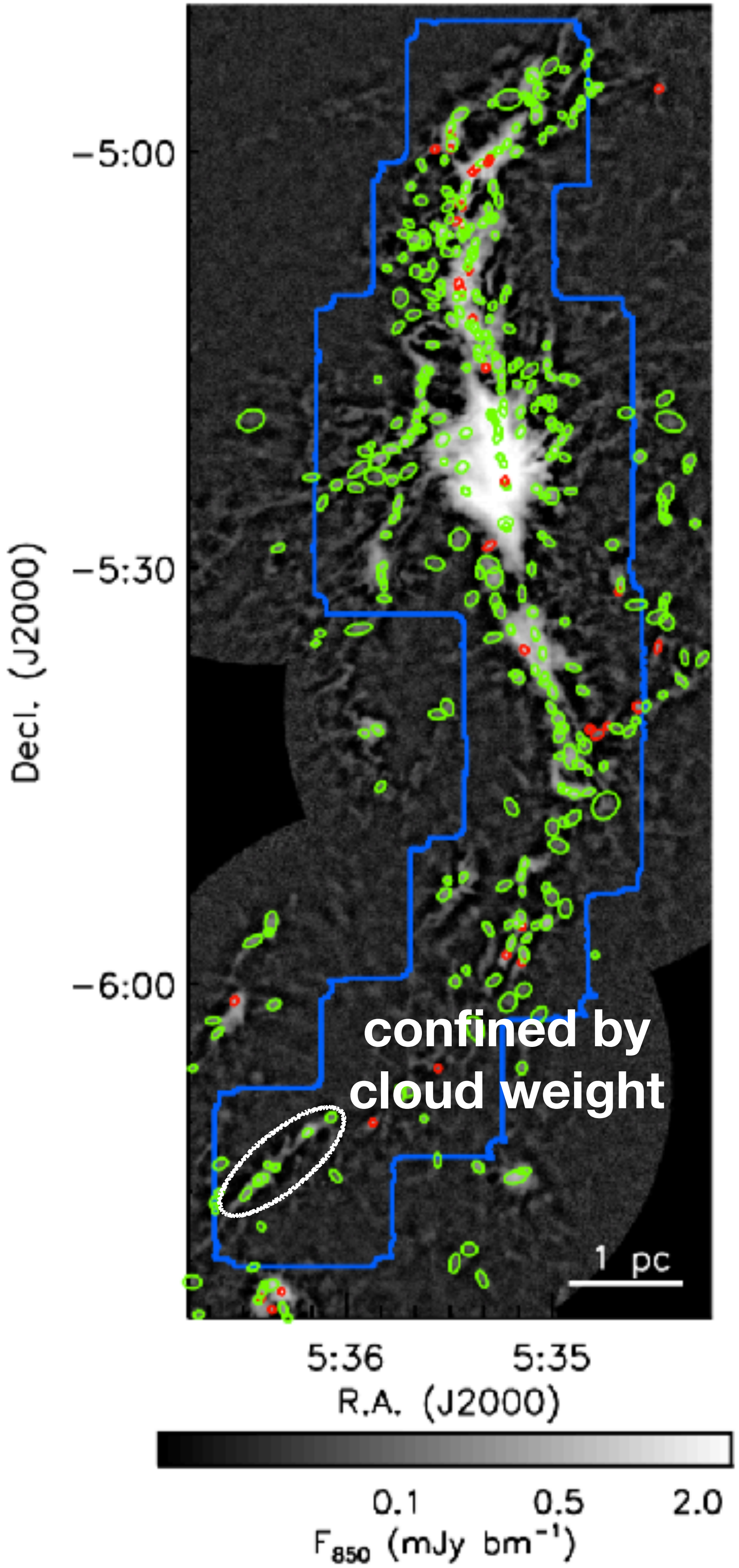

$t = 0.025$
$t = 0.025$
$t = 0.1$
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
y
−0.25
0.00
0.25
x
Grid 1024²
Grid 2048²
Grid 2048²

Comparison with Kirk et al. (2017)



confined by
magnetic surface pressure

$$\frac{1}{2}\ddot{I} = \int_V (\rho v^2 + 3P)\,dV - \int_S \mathbf{r}\cdot\mathbf{\Pi}\cdot d\mathbf{S} + \frac{1}{8\pi}\int_V B^2 dV + \boxed{\int_S \mathbf{r}\cdot\mathbf{T}_{\mathrm{M}}\cdot d\mathbf{S}} - \int_V \rho\mathbf{r}\cdot\nabla\phi\, dV - \frac{1}{2}\frac{d}{dt}\int_S (\rho\mathbf{v}r^2)\cdot d\mathbf{S}$$



confined by
cloud weight

Magnetic surface term dominates rather than cloud weight

Summary and Conclusion

1. The Stick filament is very young, excellent target for the study of filament formation
2. The filament shows fork-like structures in velocity channel maps
3. We propose a collision-induced magnetic reconnection (CMR) scenario
4. Synthetic observations reproduce observational features
5. Cores in the filament are confined by surface magnetic pressure

Future Prospectives:

1. Star Cluster Formation? yes
2. Star Formation Rate? slow?
3. More CMR Filaments in the Milky Way? we'll see...(Zeeman obs, Polarization obs)